FISH & RICHARDSON P.C.

Frederick P. Fish
1855-1930

W.K. Richardson
1859-1951

4225 Executive Square
Suite 1400
La Jolla, California
92037

Telephone
619 678-5070

Facsimile
619 678-5099

Web Site
www.fr.com

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Attorney Docket No.: 06618/290001

Box Patent Application
Assistant Commissioner for Patents
Washington, DC 20231

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WASHINGTON, DC

Presented for filing is a new provisional-to-utility patent application of:

Applicant:	ZVONIMIR Z. BANDIC; ERIC C. PIQUETTE; AND THOMAS C. MCGILL
Title:	HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER

Enclosed are the following papers, including all those required to receive a filing date under 37 CFR §1.53(b):

	Pages
Specification	7
Claims	5
Abstract	1
Declaration	2
Drawing(s)	2

Enclosures:

- Small entity statement. This application is entitled to small entity status.
- Assignment cover sheet and an assignment, 1 pages, and a separate $40.00 fee.
- Postcard.

"EXPRESS MAIL" Mailing Label Number EM153706019US
Date of Deposit March 31, 1999
I hereby certify that this correspondence is being deposited with the United States Postal Service as **"Express Mail Post Office To Addressee"** with sufficient postage on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Duncan I. Clark

Under 35 USC §119(e)(1), this application claims the benefit of prior U.S. provisional application 60/080,638, filed 4/3/98.

There are a total of 24 claims; 2 of which are independent.

Basic filing fee	$ 380.00
Total claims in excess of 20 times $9.00	36.00
Independent claims in excess of 3 times $39.00	0.00
Multiple dependent claims	0.00
Total filing fee:	$ 416.00

A check for the filing fee is enclosed. Please apply any other required fees or any credits to deposit account 06-1050, referencing the attorney docket number shown above.

If this application is found to be INCOMPLETE, or if a telephone conference would otherwise be helpful, please call the undersigned at 619/678-5070.

Kindly acknowledge receipt of this application by returning the enclosed postcard.

Please send all correspondence to:

Scott C. Harris
Fish & Richardson P.C.
4225 Executive Square, Suite 1400
La Jolla, CA 92037

Respectfully submitted,

Scott C. Harris
Reg. No. 32,030

Enclosures

ATTORNEY DOCKET NO. 06618/290001/CIT2789

Applicant or Patentee: Zvonimir Z. Bandic, et al.
Serial or Patent No.:
Filed or Issued:
For: HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) and 1.27(d)) - NONPROFIT ORGANIZATION

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

Name of Organization: California Institute of Technology
Address of Organization: 1200 East California Boulevard; Pasadena, CA 91125
Type of Organization:

[X] UNIVERSITY OR OTHER INSTITUTION OF HIGHER EDUCATION
[ ] TAX EXEMPT UNDER INTERNAL REVENUE SERVICE CODE (26 USC 501(a) and 501(c)(3))
[ ] NONPROFIT SCIENTIFIC OR EDUCATIONAL UNDER STATUTE OF STATE OF THE UNITED STATES OF AMERICA
(NAME OF STATE:)
(CITATION OF STATUTE:)
[ ] WOULD QUALIFY AS TAX EXEMPT UNDER INTERNAL REVENUE SERVICE CODE (26 USC 501(a) and 501(c)(3)) IF LOCATED IN THE UNITED STATES OF AMERICA
[ ] WOULD QUALIFY AS NONPROFIT SCIENTIFIC OR EDUCATIONAL UNDER STATUTE OF STATE OF THE UNITED STATES OF AMERICA IF LOCATED IN THE UNITED STATES OF AMERICA
(NAME OF STATE:)
(CITATION OF STATUTE:)

I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in 37 CFR 1.9(e) for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code with regard to the invention entitled HIGH POWER GALLIUN NITRIDE SCHOTTKY RECTIFIER by inventor(s) described in

[X] the specification filed herewith.
[ ] application serial no. , filed .
[ ] patent no. , issued .

I hereby declare that rights under contract or law have been conveyed to and remain with the nonprofit organization with regard to the above identified invention.

If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(c) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

*NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

Full Name: _____

Address: _____

[ ]INDIVIDUAL [ ] SMALL BUSINESS CONCERN [ ] NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status when any new rule 53 application is filed or prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Name: Adam Cochran

Title: The Intellectual Property Counsel

Address: 1200 East California Boulevard; Pasadena, CA 91125

Signature: _____ Date: 30 March 1999

87299

APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER

APPLICANT: ZVONIMIR Z. BANDIC; ERIC C. PIQUETTE; AND THOMAS C. MCGILL

"EXPRESS MAIL" Mailing Label Number EM153706019US
Date of Deposit March 31, 1999
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Duncan I. Clark

HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER

Statement as to Federally Sponsored Research

The U.S. Government has certain rights in this invention pursuant to Grant No. N00014-92-J-1845 awarded by the Navy.

Cross Reference To Related Applications

This application claims the benefit of U.S. Provisional Application No. 60/080,638, filed on April 3, 1998.

Field of the Invention

The present invention relates to gallium nitride (GaN) rectifiers for high voltage and current applications.

Background

Wide band gap materials, primarily silicon carbide (SiC) and gallium nitride (GaN) have recently become attractive substitutes to silicon in the construction of Schottky rectifiers for applications in high power and high temperature applications. Although the processing technology for SiC is more mature, in the context of Schottky rectification, GaN offers several advantages. A critical advantage is in higher electric field breakdown and

efficient manner for suppression of surface electric field breakdown. The electric field breakdown and suppression of electric field breakdown are significant factors in the design of high power devices.

Summary

The present disclosure describes a Schottky high power rectifier having a nitride insulator formed on the surface of a GaN substrate. The nitride insulator increases the electric field breakdown suppression at or near the surface of the rectifier below the insulator. In a preferred embodiment, the nitride insulator is an epitaxially grown aluminum nitride or aluminum gallium nitride.

Brief Description of the Drawings

Figures 1(A)-1(F) are a series of sectional views sequentially illustrating the steps of production of an exemplary embodiment of a Schottky rectifier in accordance with the present disclosure.

Figure 2 is an enlarged sectional view of the Schottky rectifier in Figure 1(F) with the electric field breakdown region shown in dotted lines.

Description of the Preferred Embodiments

Figures 1(A) - 1(F) show the sequential operation adopted to make a Schottky rectifier having improved breakdown resistance in accordance with a preferred embodiment. As illustrated in Figure 1(A), the fabrication of the rectifier is initiated with a substrate 10 of semiconducting material made from a sapphire or a gallium nitride (GaN) wafer material. This material is first typically cleaned with organic solvents and then loaded into an epitaxial growth reactor. The epitaxial growth process may be Molecular Beam Epitaxy or Chemical Vapor Deposition or any known equivalent process.

An GaN epitaxial film 20 is produced from such process, as illustrated in Figure 1(B). The thickness of the epitaxial film 20 is selected to support required maximum voltage properties of the rectifier. An insulator aluminum nitride (AlN) film 30 is then grown over the epitaxial film 20 in the growth reactor.

The inventors have found that the AlN film 30 passivates the surface of the GaN epitaxial film 20 to suppress surface breakdown even at reverse voltages as high as 25 kVolts and current values as great as 2 KAmperes and higher.

Once the AlN film 30 is formed, the sample is removed from the growth reactor chamber. Openings 35, 40 are then made in the AlN film 30 using conventional photolithographic patterning and

etching techniques (Figure 1(D)). An ohmic contact metal 45 is then formed by deposition and patterning in opening 35 (Figure 1(E)). Deposition and patterning is then used to form a Schottky metal contact 50 in opening 40 using photolithography (Figure 1(F)). The deposition of the metal contacts 45, 50 are formed in a liftoff type step in a known manner.

In an alternative construction, the metal contacts 45, 50 are laid down first. The AlN film is then deposited (by regrowth or sputter deposition) and patterned by liftoff.

A surface portion 60, shown in dotted lines in Figure 2, represents an electric field region at or near the surface of the GaN epitaxial film 20. This surface portion 60 is the portion of the GaN film most susceptible to breakdown in response to a very high reverse voltage or current applied to the Schottky contact. The voltage/current withstanding capability of the Schottky rectifier with AlN insulator film 30 is found to be substantially greater than a conventional GaN Schottky formed without this layer. As can be seen, the breakdown region is initiated at or near the surface of the GaN film 20. When the voltage/current withstand capability is exceeded, the Schottky rectifier device can become physically damaged, as typically may be evidenced by holes or cracks on the surface of the GaN film. The AlN film 30 thus increases this withstanding capability.

The illustrative embodiment uses AlN as the epitaxially grown insulator film. It should be understood, however, that other nitrides, including aluminum gallium nitride, may also be used.

The chemical properties of AlN and GaN materials are such that in addition to both being nitrides, growth of one on the other is done cleanly and easily. Thus, cost of manufacture is low and yield high.

Silicon and silicon carbide type rectifiers have a surface chemistry that is incompatible with that of an aluminum nitride epitaxially grown film. Accordingly, such devices would not realize any voltage withstand capability benefit from having the AlN film epitaxial film grown on a surface thereof. Indeed, the benefits of the preferred embodiments are realized by virtue of the chemical compatibility of the GaN and AlN nitride materials during the growth process.

Another disadvantage of silicon and silicon carbide rectifiers is that such materials cannot be effectively electrically isolated. A sapphire wafer, on the other hand, which is characteristically non-conductive, allows for fabrication of multiple high power components on a single substrate. This makes it possible to have multiply-coupled rectifiers on a single chip. Alternatively, one or more

rectifiers may be fabricated on a single substrate as part of a high power integrated circuit.

It should be appreciated that while Figures 1 and 2 show only a single rectifier device, a plurality of such devices may be formed simultaneously on a single wafer and then diced to yield individual components.

A Schottky rectifier device, as explained above, will have its surface and vertical geometry determined as a function of at least the desired voltage/current withstanding capabilities in the environment in which such device is to be employed. It is contemplated that a typical size top planar cross-sectional area of a typical Schottky device constructed in accordance with the present disclosure might be approximately between 1 and 10 cm^2.

A high power Schottky rectifier constructed as described herein was shown to have an applicable reverse voltage withstand capability in the approximate range between 5 kVolts and 25 kVolts, and a current withstand capability in the approximate range of 200 to 2 KAmperes.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but

only by the appended claims.

What is claimed is:

1. A high power Schottky rectifier comprising:

a substrate;

a gallium nitride epitaxial film grown over the substrate including a surface portion of a type that is susceptible to surface breakdown; and

a nitride insulator film, formed over the surface portion to suppress surface breakdown in the surface portion.

2. The high power Schottky rectifier of claim 1, wherein the nitride insulator film is one of an aluminum nitride film and aluminum gallium nitride film.

3. The high power Schottky rectifier of claim 2, wherein the nitride insulator film is an epitaxially grown film.

4. The high power Schottky rectifier of claim 3, further comprising a Schottky contact and an ohmic contact disposed in openings through the nitride insulator film extending to a surface of the gallium nitride epitaxial film on either side of the surface portion thereof susceptible to breakdown.

5. The high power Schottky rectifier of claim 4, wherein the rectifier has a planar cross-sectional area approximately between 1 and 10 cm^2.

6. The high power Schottky rectifier of claim 5, wherein the rectifier has a reverse voltage withstand capability in the approximate range between 5 kVolts and 25 kVolts.

7. The high power Schottky rectifier of claim 5, wherein the rectifier has a current withstand capability in the approximate range between 200 and 2000 Amperes.

8. The high power Schottky rectifier of claim 1, wherein the substrate is sapphire.

9. The high power Schottky rectifier of claim 1, wherein the substrate is a gallium nitride material.

10. The high power Schottky rectifier of claim 1, further comprising a Schottky contact and an ohmic contact disposed in openings through the nitride insulator film extending to a surface of the gallium nitride epitaxial film on either side of the surface portion thereof susceptible to breakdown.

11. The high power Schottky rectifier of claim 1, wherein the rectifier has a planar cross-sectional area approximately between 1 and 10 cm^2.

12. The high power Schottky rectifier of claim 1, wherein the rectifier has a reverse voltage withstand capability in the approximate range between 5 kVolts and 25 kVolts.

13. The high power Schottky rectifier of claim 1, wherein the rectifier has a current withstand capability in the approximate range between 200 and 2000 Amperes.

14. A method of fabricating a high power Schottky rectifier device with high suppression of surface electric field breakdown comprising :

producing a gallium nitride epitaxial film on a substrate; and

growing a nitride insulator film over the gallium nitride epitaxial film.

15. The method of claim 14, wherein said nitride insulator film is one of an epitaxially grown aluminum nitride film and an aluminum gallium nitride film.

16. The method of claim 15, further comprising:

creating first and second openings through the nitride insulator film extending to the surface of the gallium nitride epitaxial film; and

forming a Schottky contact and an ohmic contact in associated ones of the first and second openings.

17. The method of claim 16, wherein the rectifier has a planar cross-sectional area approximately between 1 and 10 cm^2.

18. The method of claim 17, wherein the gallium nitride epitaxial film is grown on a sapphire wafer material.

19. The method of claim 17, wherein the gallium nitride epitaxial film is grown on a gallium nitride wafer material.

20. The method of claim 17, wherein the gallium nitride epitaxial film is grown on an electrically non-conductive wafer material.

21. The method of claim 17, wherein said high power rectifier device is one of multiple high power devices formed on a single wafer material.

22. The method of claim 21, wherein said multiple high power devices includes at least two rectifier devices.

23. The method of claim 21, wherein said multiple high power devices constitute an integrated circuit.

24. The method of claim 14, further comprising:

creating first and second openings through the nitride insulator film extending to the surface of the gallium nitride epitaxial film; and

forming a Schottky contact and an ohmic contact in associated ones of the first and second openings.

HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER

Abstract of the Disclosure

A Schottky high power rectifier having a nitride insulator formed on the surface of a GaN substrate. The nitride insulator increases the electric field breakdown suppression at or near the surface of the rectifier below the insulator. In a preferred embodiment, the nitride insulator is an epitaxially grown aluminum nitride insulator.

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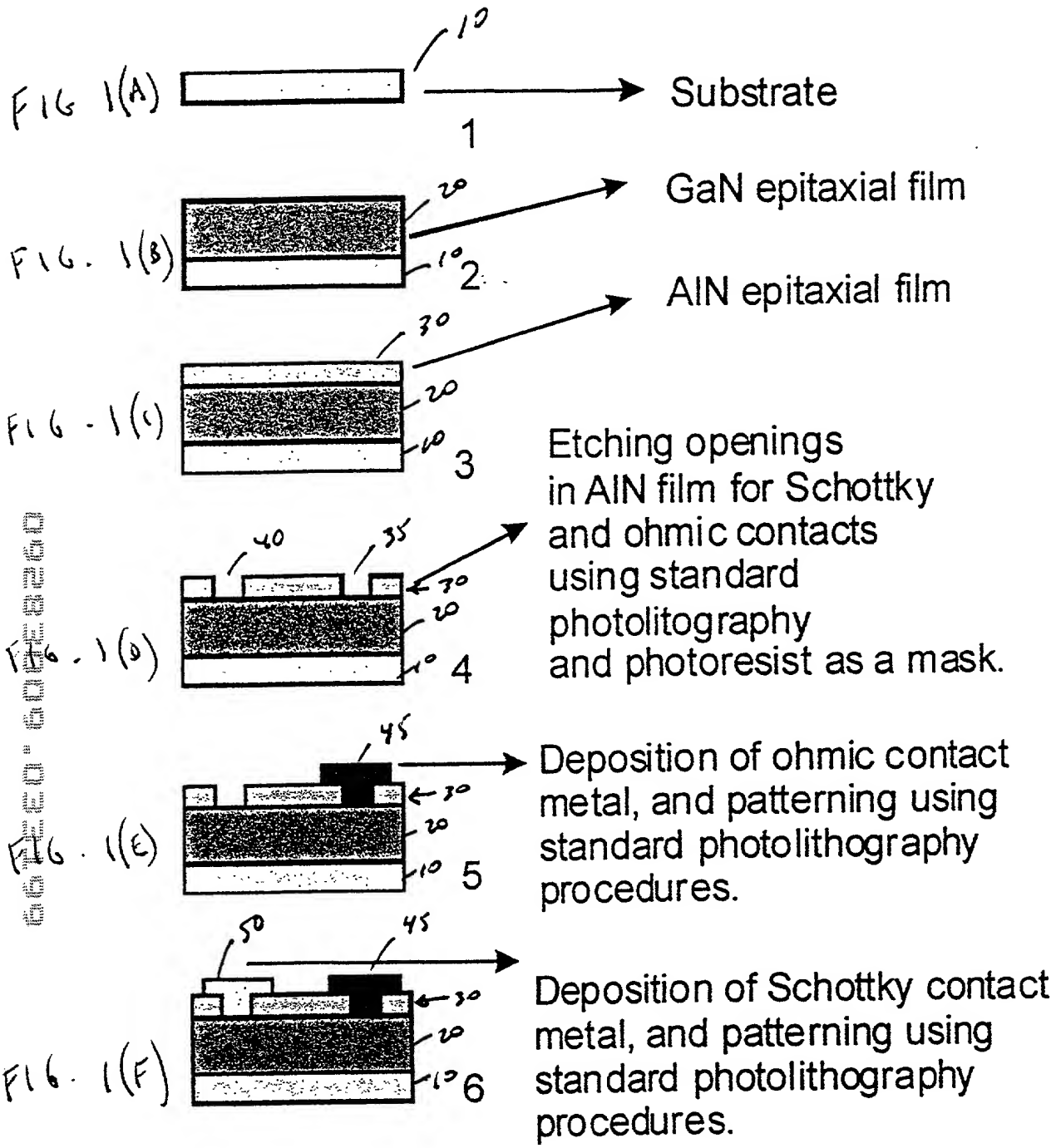
FIG 1(A)
10
Substrate
1
FIG. 1(B)
20
10
GaN epitaxial film
2
AlN epitaxial film
FIG. 1(C)
30
20
10
3
FIG. 1(D)
40
35
30
20
10
4
Etching openings in AlN film for Schottky and ohmic contacts using standard photolitography and photoresist as a mask.
FIG. 1(E)
45
30
20
10
5
Deposition of ohmic contact metal, and patterning using standard photolithography procedures.
FIG. 1(F)
50
45
30
20
10
6
Deposition of Schottky contact metal, and patterning using standard photolithography procedures.

FIG. 1

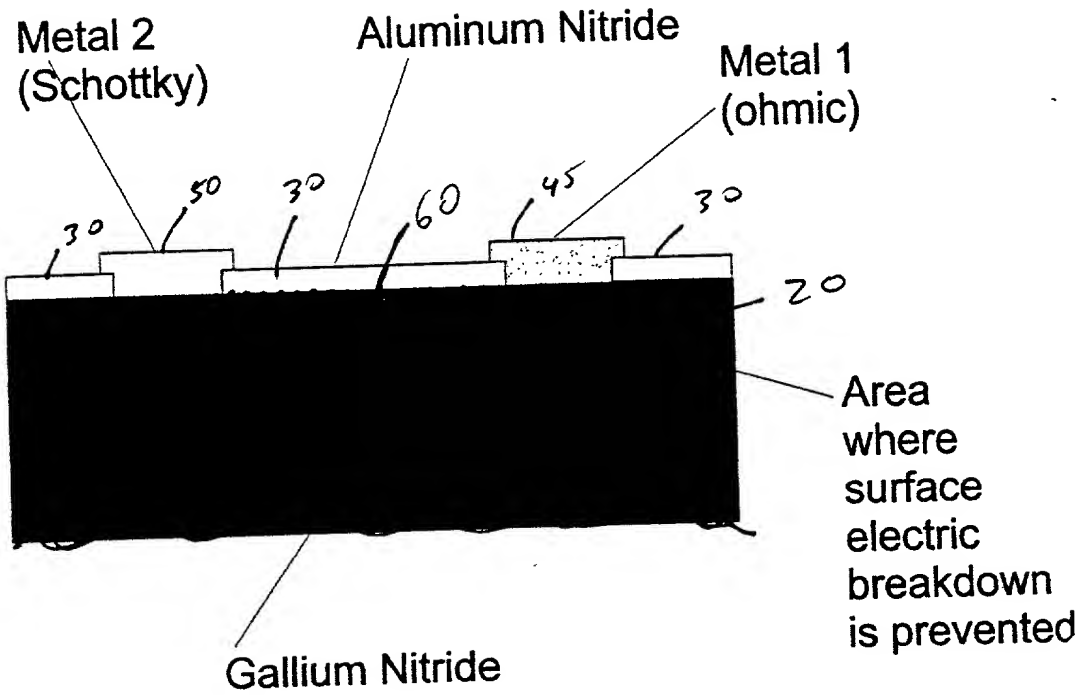

FIG. 2

PATENT
ATTORNEY DOCKET NO: 06618/290001/CIT2789

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled HIGH POWER GALLIUM NITRIDE SCHOTTKY RECTIFIER, the specification of which

■ is attached hereto.
☐ was filed on _____ as Application Serial No. _____
and was amended on _____.
☐ was described and claimed in PCT International Application No. _____
filed on _____ and as amended under PCT Article 19 on _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information I know to be material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim the benefit under Title 35, United States Code, §119(e)(1) of any United States provisional application(s) listed below:

U.S. SERIAL NO.	FILING DATE	STATUS
60/080,638	April 3, 1998	■ Pending ☐ Issued ☐ Abandoned

I hereby appoint the following attorneys and/or agents to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: Scott C. Harris, Reg. No. 32,030; William J. Egan, III, Reg No. 28,411; David L. Feigenbaum, Reg. No. 30,378; John F. Land, Reg. No. 29,554; Ralph A. Mittelberger, Reg. No. 33,195; Hans R. Troesch, Reg. No. 36,950; John R. Wetherell, Jr., Reg. No. 31,678; Bing Ai, Reg No. 43,312; and George C. Pappas, Reg. No. 35,065, of Fish & Richardson P.C.

Address all telephone calls to Scott C. Harris at telephone number 619/678-5070.

Address all correspondence to Scott C. Harris, Fish & Richardson P.C., 4225 Executive Square, Suite 1400, La Jolla, CA 92037.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patents issued thereon.

Full Name of Inventor: Zvonimir Z. Bandic

Inventor's Signature: Bandic jr Date: 03/30/99

Residence Address: _____

Citizen of: _____

Post Office Address: _____

PATENT
Attorney Docket No. 06618/290001/CIT 2789

COMBINED DECLARATION AND POWER OF ATTORNEY CONTINUED

Full Name of Inventor: Eric C. Piquette

Inventor's Signature: Eric C Piquette Date: 3/30/99

Residence Address: ____________________

Citizen of: ____________________

Post Office Address: ____________________

Full Name of Inventor: Thomas C. McGill

Inventor's Signature: Thomas McGill Date: 3/30/99

Residence Address: ____________________

Citizen of: ____________________

Post Office Address: ____________________

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